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LUMINESCENT SMOKE GENERATION

FEASIBILITY STUDY

(Final Report)

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NAVAL TRAINING DEVICE CENTER

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ABSTRACT

The smoke fuels described in this report serve, in conjunction with the X3H14 smoke generator, to accomplish smoke clouds which are sensitive to ultra-violet light (UV) excitation; that is, the smoke cloud is luminescent when exposed to GE BLB 40 W and GE BL 40 W ultra-violet ray generating bulbs. The smoke clouds, visible under UV lamps, are luminescent for a few seconds and then dissipate rapidly and cleanly, leaving no fluorescent residue. The smoke fuels are stable at room temperatures and generate luminescent clouds which are non-toxic under normal conditions.

It was demonstrated in this program that neither the X3H14 nor the operating procedures, used with the non-luminescent fuels, need be changed to use the luminescent fuels.

This report covers the literature study of luminescence; the experimental studies with the generator; candidate fuels and the pertaining variables which affect the resulting smoke clouds; and a brief stability study of the liquid smoke fuel.

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FOREWORD

Device X3H14, designed to simulate explosions, was developed under a sponsored program to satisfy requirements originating with the U.S. Navy Amphibious School, Little Creek, Virginia. Designed for use in the Amphibious Training Demonstrator, Device 16-F-1, the X3H14 prompted the formulation of a smoke fuel, for use in conjunction with the generator, to produce a smoke cloud which is easily generated, non-toxic and reliable. The device and smoke fuel were demonstrated in November of 1964 and they were subsequently accepted.

In an effort to expand the smoke-generating phenomenon and more fully utilize the 16-F-1, a secondary program was initiated. This program was designed to study the feasibility of formulating a fuel capable of producing smoke sensitive to UV. Moonlight nighttime conditions could then be simulated by using UV sources to illuminate the smoke cloud. Results reported in April 1966 indicate a definite potential for formulation of such a fuel. Several suggestions, based on techniques in the proposal, arose from this study. These suggestions prompted another study, the results of which are the basis for this report.

T. H. McK— for
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PROBLEM DEFINITION

INTRODUCTION

An extensive research program, conducted by Missouri Research Laboratories, resulted in the smoke fuel presently used in the smoke generating device, X3H14. This formulation consists of 80 parts kerosene, 20 parts methyl salicylate and 1 part glycerin. Utilized in the X3H14, this formulation accomplishes a generous white cloud. The cloud dissipates rapidly, is non-toxic and relatively odorless. The combination of this fuel and the smoke generator results in an economical, effective and reliable smoke cloud source.

The purpose of this report is to describe the methods, test results and conclusions that comprise the effort of expanding the potential of the smoke generating device into the realm of fluorescent response. This report covers research over a period approximating five months, in search of a fuel to meet the sponsor's requirements.

REQUIREMENTS

The requirement of this task is the development and evaluation of a fuel (or fuels) compatible with and capable of being used in the basic X3H14 smoke generator, to effect a luminous cloud upon exposure to UV excitation. Another part of the requirement is that the fuel be stable in its liquid form and, when used to generate smoke, produce a cloud which is compatible with the NTDC training complex; that is, it must be sensitive to the existing ultra-violet light sources, non-toxic in its vapor form, completely quenched of luminescent response upon dissipation of the cloud and capable of being used in the existing smoke generator with little or no change in the design.

SUMMARY

In order to satisfy the requirements generated in this task, several areas of investigation were included in this program. To determine sources of fluorescent response and to ascertain the state of the art, literature was to be surveyed. The next step involved a study of the smoke generating device to determine the potential and the limitations of the smoke generating mechanism. When the most promising candidates for fluorescence had been procured, they were to be tested in the apparatus varying the solvent and the concentration. This physical testing was expected to prompt further work, using related compounds. Materials for these compounds would be procured and tested and when the most promising formulations were ascertained, the stability of the fuel and the characteristics of the smoke cloud were to be determined. The formulations were then to be evaluated in terms of the requirements. This was the suggested program.

SECTION II

INVESTIGATION PROCEDURES

LITERATURE RESEARCH

Initial survey of texts in public and university libraries indicated no existence of publications dealing with the generation of fluorescent smoke. For this reason, the requirement was separated into phases of the phenomenon and the search was continued into the categories of smoke, aerosols, pyrotechnics, fluorescence, phosphorescence, luminescent ultra-violet light phenomenon, light phenomenon and colored light theory.

The literature was researched for mechanisms of smoke generation and for fuel systems capable of producing smoke clouds. The field of forms of luminescence was surveyed in detail for gases, or aerosols of liquids or solids, which are fluorescent, and for mechanisms of fluorescent generation in gases or aerosols. Attempts to further divide the phenomenon in terms of the physics of light and color moved into fields too abstract and removed to constitute a quick and efficient method back to the total of the fluorescent phenomenon.

It was found that the field of smoke generation has recently found impetus from the direction of air pollution control. However, the emphasis is on elimination rather than generation. Pyrotechnics offer formulations for smoke generation, but the references appear to have remained relatively unchanged for years. The field of luminescence shows more activity due to a sudden interest in medicine and chemical analysis in the field of fluorometry. Fluorescence is also a useful tool in quality control and the arts.

TESTING APPARATUS

The testing was conducted in a dark room. A fluorescent light fixture was fitted with GE black light bulbs and hung about seven feet above the smoke generating apparatus. Smoke clouds were checked with GE BL and GE BLB bulbs, which are capable of generating UV. Smoke clouds were also checked by exposing them to standard fluorescent lighting.

The smoke generator was set up with a variable air pressure of eight to twelve pounds per square inch gauge generated in a filtered air line. The air line was connected to the aspirator on the smoke generator.

In the experimental assembly, the solenoid controlling the fuel feed and the control determining the temperature of the heating coils were powered separately. The solenoid control was activated directly by plugging into a standard outlet (110 V., 60 cycle A.C.). The feed to the coils was controlled by a rheostat to allow some variation in the coil temperature.

The smoke generator design, showing all major components, is illustrated in figure 1. The details of the standard circuit control and pneumatic line attachment are shown in figure 2.

The smoke generating mechanism is described in the following. In the smoke generator, the fuel is atomized into a heating chamber. Here it is converted into gases which are expelled through the chimney, located above the heating chamber. The impelling force behind the aerosolizing of the fuel is a driving air pressure of eight to twelve PSIG. The heating coils, maintained (in standard operation) at about 400°F. and in contact with the aerosolized fuel, generates a gaseous cloud which is discharged through the chimney. The cooler air above the chimney regenerates some liquid and solid particles (condensation) which form the cloud to be tested.

TESTING PROCEDURES

The physical testing of the fuel candidates begins with a study of the solution characteristics of the candidate chemicals. The behavior of the chemical in several solvents, in terms of the concentration at saturation and the effect of solvent upon the fluorescence of the solution, was investigated. The purpose of this investigation was to determine several possible solvents for the candidate to allow for possible interference of the solvent with the fluorescent response of the cloud. The effect of the solvent in terms of quenching fluorescence, obscuring or diluting the fluorescent response (by forming too much non-fluorescent smoke) or heightening the fluorescent response was investigated after different solvent systems had been determined. The effects of concentration of fluorescent chemical in the fuel was also included because the texts indicate that a concentration too high can quench a material's fluorescent response as readily as one too low can elicit a weak response.

The purity of chemicals and solvents is paramount in this study because fluorescence can easily be quenched or elicited by an impurity in a fluorescent material. The danger of quenching fluorescence with impurities is obvious. However,

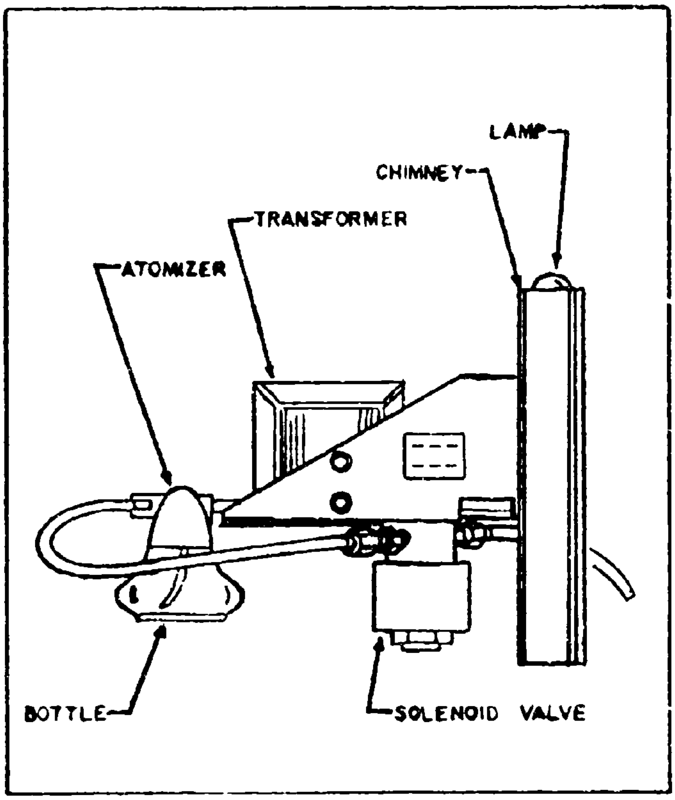

Figure 1. Smoke Generator

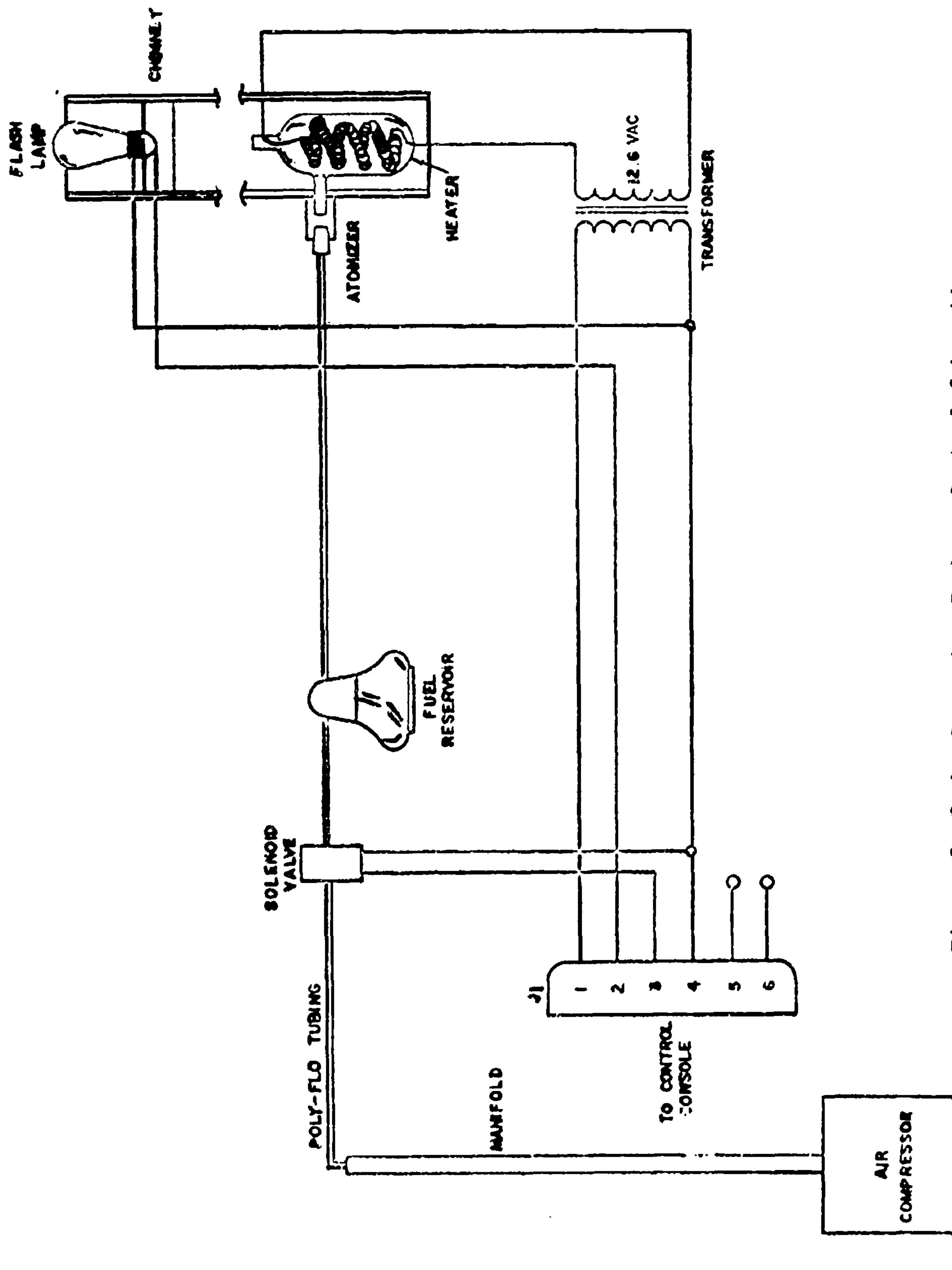

Figure 2. Smoke Generator Package Control Schematic

eliciting a good fluorescent response due to an unknown impurity would require a very intensive study just to determine the repeatability of an effective fuel. Without knowing the source of the activity, the success of future formulations would depend on chance. For this reason, procedures were conducted so as to maintain known conditions of formulation and to avoid introducing unknown factors or materials.

During generation of the cloud, the air pressure to the atomizer and the voltage to the coils were varied in an attempt to create better conditions for the generation of a fluorescent cloud. Variation of the air pressure was conducted to accomplish the right concentration of fuel to obtain the maximum cloud generation. The voltage to the heating coils was varied to protect heat sensitive compounds from being destroyed, when only sublimation or warming of aerosolized particles was desirable.

Testing was conducted with exposure to standard fluorescent lighting, ultra-violet light (with a high concentration of visible light) and with filtered black light (primarily UV rays). To accomplish this, a standard fixture was fitted with GE BL 40 W bulbs in addition to the standard fluorescent lighting.

When the most promising candidates were formulated, they were maintained in surveillance to determine the stability of the fuel; they were checked with respect to fluorescent response periodically and the results compared to freshly prepared formulations.

In addition to checking the behavior of the formulation in storage, the behavior of the fuel in the smoke generator was checked for instability of the fuel or damage to the generator. Within the generator, the fuel is in contact with glass in the reservoir and the heating column; with polyethylene in the dip tube; and with various metals throughout the operation, such as, stainless steel, brass and nichrome.

EVALUATION CRITERIA

During evaluation of the generated cloud, several characteristics were investigated in light of the requirement. The density of the cloud, in terms of fluorescent response and the opacity of the cloud, was evaluated. The odor and the toxicity of the cloud were checked along with any tendency to a fluorescent residue on the area surrounding the site of generation. The duration of the response and the extent of cloud dissipation are among the considerations made in terms of the quality of the response.

In addition to the evaluation of the response, the fuel was tested for stability in regard to light and heat, to evaporation, and to any reactions between solvent and the active ingredients. The fuel was also tested for continued fluorescence, over a period of two months, by exposing it to the light and temperatures of room conditions.

SECTION III

DATA ACCUMULATION

SMOKE GENERATION (LITERATURE RESEARCH)

Several mechanisms for smoke generation were described in the literature. These break down to two basic approaches. The first approach involves incomplete combustion of oil resulting in dense black smoke. The second approach is more mechanical and comprises various methods. Two such methods consist of injecting warmed atomized oil into a cool atmosphere which results in a fog or cloud of oil droplets, and injecting aerosolized chemicals into the air which can react with the humidity in the air to form fog. Most of the methods described were for large scale generation of smoke in an open area, however, and are dependent on diffusion for warding off such problems as odor and toxicity. The literature did suggest atomization as a means of producing smoke on a small scale in a laboratory.

LUMINESCENCE TECHNIQUES (LITERATURE RESEARCH)

There are several methods for eliciting a luminescent response. Luminescence is defined as the light resulting from a return of a compound from an excited state to its normal energy state; however, the light emission has a higher energy release than would occur from temperature radiation alone. Light emission which occurs only during excitation is termed fluorescence; that which lingers after excitation is termed phosphorescence. The forms of luminescence which appeared possibly useful in the desired mechanism included luminescence based on several different sources. These sources include gentle heating resulting in thermoluminescence, chemical reaction with energy release resulting in chemiluminescence and UV excitation resulting in photoluminescence.

It was determined from the literature that the problem of eliciting a quality response is complex. There are a number of factors that affect the response: impurities will likewise quench or enhance a fluorescent response; heat may cause thermoluminescence or may quench fluorescence; if concentration is low the response may be too weak, if high it may quench its own response; and the solvent may alter the response. This is an indication of the variables involved in eliciting the most effective response.

PYROTECHNICS (LITERATURE RESEARCH)

The field of pyrotechnics was investigated as a source of smoke generation and, in particular, colored smoke. The texts which were studied indicate that, over the years, there has been relatively little change in fuel formulations for display or signal smoke generation. It was hoped that some of the heat-insensitive dyes used in production of colored smokes might also be sensitive to UV excitation. A number of chemicals were purchased and tested in the original smoke fuel formulation with negative results in terms of fluorescent response elicited. The candidate chemicals are listed in table 1.

TABLE 1. PYROTECHNIC DYES FOR COLORED SMOKE DISPLAYS

*SMOKE COLOR	CHEMICAL	SOLUTION FLUOR.	SMOKE FLUOR.
yellow	auramine-O Fisher Scientific A968	none	none
yellow	auraminehydrochloride Fisher Scientific 1247-T	none	none
yellow	N,N-dimethyl-p-naphthylazo-aniline Fisher Scientific 2535	none	none
red	1-methylaminoanthraquinone Fisher Scientific 5680-P	none	none
orange	a-aminoanthraquinone Fisher Scientific 1387-P & auramine-O	none	none
orange	1-amino-8-chloranthraquinone K & K Laboratories 3416 & auramine-O	none	none
green	1,4-di-p-toluidinoanthra-quinone K & K Laboratories 4601	none	none
violet	1,4-diaminoanthraquinone K & K Laboratories 12648	none	none

These dyes were tested, dissolved to their saturation point in the original smoke formulation based on kerosene, glycerin and methyl salicylate. The dyes were only slightly soluble.

* This is the suggested color of smoke having this dye or set of dyes in the formulation.

FLUORESCENT CHEMICALS

After an unsuccessful attempt to use heat-insensitive dyes, the investigation was turned to a study of fluorescent materials. The texts that were studied emphasized fluorescent solutions lacking reference to useable fluorescent gases. This being the case, the data had to be extrapolated to cover the aerosolized or gaseous forms of the fluorescent solutions. Those materials with the most colorful solution responses were further investigated for stability when exposed to heat. Based on this study, several compounds were chosen for trial formulations.

Of the materials tested, the most promising candidate appeared to be crude anthracene. Even when checked against refined anthracene, the crude gave a better response. Based on this data, the response was credited to the presence of some impurity. From the literature, it was noted that the separation of anthracene from tetracene (naphthacene) during synthesis of this compound is described as difficult. Further testing with tetracene indicated that the best response was achieved with a combination of tetracene and anthracene.

At this point, the study was divided into the investigation of the effects various solvent systems have on the quality of the response (which will be reported later); and into an investigation of compounds similar in structure to anthracene and tetracene. Table 2 lists the chemicals and related solvents which were tested. The fluorescent results of the tests also appear in this table. The compounds, listed on table 2, which follow the combination of tetracene and anthracene were chosen because of their similarity in structure to this combination; they consist primarily of chains made up of adjacent benzene rings. The response of these materials was further heightened by the use of mineral spirits as the solvent in lieu of the three shown on table 2.

It appears that the fluorescent response was due to the solvents, xylene and dibromomethane when they were used. It was further noted that in studies using xylene and kerosene the nonfluorescent smoke generated tends to mask the fluorescent response.

SOLVENT VARIATIONS

Because the solvent can affect the quality of the fluorescent response, the fluorescent chemicals were tested in several solvents. These include ethanol, methanol, kerosene, mineral spirits, dibromomethane, methylene chloride and xylene.

TABLE 2. SOLVENT STUDY OF FUEL CANDIDATE CHEMICALS

SOLVENT:	Kerosene(Fisher K-10)		Xylene(Fisher X-5)		Dibromomethane(Fisher 1881)	
CHEMICALS/ SUPPLIER	FLUOR. SOLUTION	SMOKE RESPONSE	FLUOR. SOLUTION	SMOKE RESPONSE	FLUOR. SOLUTION	SMOKE RESPONSE
Benzoin Fisher 302P	colorless	white, nonfluor.	lt.yellow-green	white, slight fluor.	lt.yellow	white, slight fluor.
Salicylaldazine Fisher 6563	colorless	white, nonfluor.	yellow-green	white, slight fluor.	yellow	white, slight fluor.
Acridine orange Fisher A971	colorless	white, nonfluor.	yellow-green	white, slight fluor.	yellow	white, slight fluor.
Rhodamine B Fisher NA702	pink tinge	white, nonfluor.	red	white, slight fluor.	red	white, slight fluor.
Fuchsin acid Fisher F97	colorless	white, nonfluor.	colorless	white, slight fluor.	UV absorber	white, slight fluor.
Fuchsin basic Fisher F98	colorless	white, nonfluor.	colorless	white, slight fluor.	UV absorber	white, slight fluor.
Anthracene Fisher 480P	yellow tinge	white. slight fluor.	yellow tinge	white, slight fluor.	no test	no test
Anthracene Fisher 480	clear	white, nonfluor.	clear	white, slight fluor.	clear	white, slight fluor.
Tetracene Fisher 4785	orange	slight green fluor.	orange	white, slight green	orange	slight green fluor.
Anthracene/ Tetracene	yellow-orange	pale green, fluor.	yellow-orange	pale green, fluor.	yellow orange	intense green, fluor.
Chyrsene Fisher 4217	colorless	white, nonfluor.	colorless	white, slight fluor.	colorless	white, slight fluor.
Pentamethyl-benzene Fisher 3106	colorless	white, nonfluor.	colorless	white, slight fluor.	colorless	white, slight fluor.

TABLE 2. SOLVENT STUDY OF FUEL CANDIDATE CHEMICALS (continued)

SOLVENT:	Kerosene(Fisher K10)		Xylene(Fisher X5)		Dibromomethane(Fisher 1881)	
CHEMICALS/ SUPPLIER	FLUOR. SOLUTION	SMOKE RESPONSE	FLUOR. SOLUTION	SMOKE RESPONSE	FLUOR. SOLUTION	SMOKE RESPONSE
4,4-dibromo-biphenyl Fisher 2724P	colorless	white, nonfluor.	colorless	white, slight fluor.	colorless	white, slight fluor.
Fluoranthene Fisher 5512P	not tested	not tested	yellow-green	some white, fluor.	yellow-green	slight white, fluor.
Acenaphthene Fisher 597	colorless	white, nonfluor.	colorless	some white, fluor.	colorless	white, slight fluor.
Dibenz(a,h) anthracene Fisher 3272	colorless	white, nonfluor.	colorless	white, slight fluor.	colorless	white, slight fluor.
Benze(a)pyrene Fisher 4941	yellow	white, nonfluor.	yellow-green	white, slight fluor.	yellow-green	white, slight fluor.

Solvents such as ethanol and methanol would not dissolve sufficient quantities of the candidate chemicals to warrant much use in this study. As it was, the most promising materials were generally of limited solubility in any of the solvents tested. The most efficient solvents were used in the study prior to determination of the most promising chemicals. This is noted on table 2. Table 3 represents the solvent study conducted with the most promising chemicals.

CONCENTRATION VARIATIONS

The literature indicated that the fluorescent response is dependent upon the concentration of chemical in the solvent. A concentration too high will quench fluorescence as readily as too low a concentration. Variations of the concentration of the candidate chemicals in various solvents are described in table 3. Because of the limited solubility of most of the chemicals, saturated solutions were used in the initial search for a fluorescent response of any intensity. Due to the danger of clogging the aspirator, however, saturated solutions, having the probability of precipitation, were avoided.

The best responses were elicited with the combinations: 4% fluoranthene in mineral spirits; and 1% anthracene and 0.04% tetracene in xylene. The first combination elicits a smoke cloud which fluoresces white when exposed to UV. The second combination accomplishes a dull purple cloud which fluoresces an intense green just seconds after the cloud is formed.

APPARATUS STUDY

Variation of the aspirating pressure failed to accomplish any noticeable variation in the quality of the fluorescent response. Likewise, variation of the temperature of the heating coils offered no advantage. Since it is desireable that the operation of the apparatus be changed as little as possible, it is fortunate that testing indicated no real need for any variations.

When exposed to normal fluorescent lighting, the fluoranthene fuel in mineral spirits realizes a smoke cloud comparable to the original formulation for simulated explosion in daylight. Under the BL 40 W lamps which admit a mixture of ultra-violet and visible light, the fuel accomplishes a good cloud but its fluorescence is diminished. Under the BLB 40 W bulbs, the cloud fluoresces in white light response. The second formulation (see CONCENTRATION VARIATIONS above) offers little visible response when exposed to standard fluorescent lighting, but elicits a pale green cloud when exposed to a

TABLE 3. SOLVENT AND CONCENTRATION VARIATIONS

FUEL FORMULATION	SMOKE RESPONSE
1% fluoranthene in xylene	very slight fluor.
2% fluoranthene in xylene	slight fluor.
2% fluoranthene in acetone	slight to medium fluor.
4% fluoranthene in acetone	slight to medium fluor.
2% fluoranthene in dibromomethane	slight to medium fluor.
Saturated solution of fluoranthene in mineral spirits	intense white fluor.
**2 to 4% fluoranthene in mineral spirits	intense white fluor.
4% fluoranthene/2% anthracene in dibromomethane	slight to medium fluor.
2% fluoranthene/1% anthracene in 50% dibromomethane /50% mineral spirits	slight to medium fluor.
0.02% tetracene in xylene	slight fluor.
0.04% tetracene in xylene	slight fluor.
0.02% tetracene in methylene chloride	slight fluor.
0.02% tetracene in dibromomethane	slight fluor.
1% anthracene 0.02% tetracene in mineral spirits	medium to intense green fluor.
2% anthracene 0.02% tetracene in mineral spirits	medium to intense green fluor.
1% anthracene 0.02% tetracene in xylene	medium to intense green fluor.
**1% anthracene 0.04% tetracene in xylene	most intense green fluor.
2% anthracene 0.02% tetracene in xylene	medium to intense green fluor.

TABLE 3. SOLVENT AND CONCENTRATION VARIATIONS (continued)

FUEL FORMULATION	SMOKE RESPONSE
2% anthracene 0.04% tetracene in xylene	medium to intense green fluor.
1% anthracene 0.02% tetracene in dibromomethane	intense green fluor.
2% anthracene 0.02% tetracene in dibromomethane	intense green fluor.
1% anthracene 0.02% tetracene in methylene chloride	medium green fluor.
2% anthracene 0.02% tetracene in methylene chloride	medium green fluor.

** These formulations were chosen as the most promising smoke fuel candidates.

mixture of UV bulb and visible light (GE BL 40 W bulb). It accomplishes an intense green fluorescence when exposed to the GE BLB 40 W bulb.

SUMMARY

After testing a number of chemicals with concurrent variations in concentration and solvents, two smoke fuel formulations were selected. These formulations have been tested in the smoke generating apparatus and were exposed to standard lighting, unfiltered UV, and filtered black light. In determining the effects of various parameters on the fluorescent response, information was gathered relative to the sensitivity of fluorescent response.

SECTION IV

DATA EVALUATION

SMOKE FUEL FORMULATIONS

The formulation involving fluoranthene is easily prepared, consisting of 4 grams of fluoranthene (Fisher 5512P) dissolved in 100 ml of mineral spirits. Fluoranthene dissolves readily, with a moderate amount of stirring, forming a pale yellow solution with a blue-white solution fluorescence.

The formulation utilizing anthracene and tetracene requires more preparation due to the insolubility of tetracene. 1 gram of anthracene (Fisher 480-X) and 0.04 grams of tetracene (naphthacene)(Fisher 4785) are placed in 100 ml of xylene. Extensive stirring is required to complete solution of these materials. The solution is best completed by placing the mixture on a magnetic stirrer for about 24 hours of cumulative stirring. The solution is a darker yellow than the fluoranthene fuel and fluoresces yellowish green in solution.

SMOKE CLOUD CHARACTERISTICS

The cloud formed with the anthracene-tetracene fuel exhibits intense green fluorescence. Tested with the BLB (black light bulb), the bulb emitting the more intense ultra-violet rays, the response is intense up to a distance of 10 feet between the generator orifice and the light source; at 20 feet, the response is only fair. Under simulated moonlight conditions, using the GE BL 40 W bulb, the response is in the fair to good range. Under normal fluorescent light or in daylight conditions, the smoke fuel capable of only a poor response.

The fluoranthene based fuel accomplishes a good to intense white cloud, when illuminated by the BL 40 and the BLB 40 bulbs, tested at distances up to twenty feet and under daylight conditions. With the UV exposure, the cloud is an intense white. The white smoke is equally visible but not luminescent in daylight.

Both smoke fuels accomplish smoke clouds which dissipate rapidly and leave no fluorescent residue. It was noted during testing that an increase in aspiration pressure can supply more fuel than can be aerosolized. In these instances, droplets of the fuel built up near the orifice of the generator. Of the two fuels, the resulting fluorescent residue was more apparent with the anthracene-tetracene. This residue formation can be avoided by properly adjusting the aspirating air pressure.

SMOKE FUEL PROPERTIES

The anthracene-tetracene based formulation is dissolved in xylene. Xylene has a boiling point of about 140°C. and is toxic in high vapor concentrations. However, it is unlikely that sufficiently high concentrations would be reached in a room of average size without noticeable increase in odor. This fuel preparation is dark golden color which lightens with time. Because the fuel is nearly saturated with regard to tetracene, there is some slight precipitation evident in the fuel. However, short periods of exposure to lowered temperatures will not precipitate any appreciable amount of the chemicals.

The formulation based on fluoranthene forms a gold colored solution when the active ingredient is dissolved in mineral spirits. The boiling point of this solution lies around 160°C. and any danger of toxicity from the cloud requires a noticeably high concentration of vapors.

STORAGE CHARACTERISTICS

It is recommended that these formulations be packaged in glass containers with tight fitting screw cap lids; the solvents in these formulations probably would attack plastic bottles. Exposure of these formulations to room conditions of humidity and temperature, with intermittent testing over a period of about three months, indicates no deterioration in the efficiency of the response.

APPARATUS MODIFICATION

Variations in the current fed to the heating coils, to determine the effect in alteration of the temperature, indicated that lowering the temperature of the coils did not increase the response. Evidently the high temperature of the coils does not destroy the fluorescent ingredient. It was suggested in earlier testing that the high temperature of the coils was responsible for complete combustion of fluorescent organic chemicals and thus no fluorescent particles or liquid droplets were formed or found in the resulting smoke cloud.

The aspirating pressure was increased simultaneously with the variations in current, in hopes that more fuel would be fed through the coils, increasing the concentration of fluorescent matter in the cloud. Testing indicated that the increased pressure did not increase the response.

Because these variations were not needed and because it was preferable to use the apparatus without variation, further testing was curtailed. The response of the fuels in generating smoke was sufficiently good to make variations in procedure unnecessary.

SECTION V

CONCLUSION

SMOKE FUEL

The smoke fuel based on fluoranthene is the most versatile of all formulations tested. The smoke which results from its utilization in the smoke generator is efficient in daylight, under fluorescent light, under the BL 40 W UV (simulated moonlight) and under BLB 40 W UV. Exposure by the BLB results in a dense cloud with white fluorescence. The remaining conditions consist of a combination of fluorescence and visible white smoke (response to visible light). The same directions and conditions prevail in the X3H14 smoke generator with either the standard smoke fuel based on kerosene or this smoke fuel being used.

The smoke fuel is stable in its liquid form. In regard to toxicity, the odor of the cloud would be irritating before the vapors reached the toxic level. Normally, the fumes would not reach this level in a room of average size. Also, the cloud dissipates rapidly and does not leave any fluorescent residue on the surrounding area.

In terms of stability of the liquid fuel, toxicity of the cloud vapors, and prompt dissipation without apparent residue, the smoke fuel formulation based on anthracene and tetracene is comparable to the formulation previously described. However, the response is not quite as intense under the BL 40 W ultra-violet light (simulated moonlight) and the response in daylight is poor.

Both smoke fuels meet the requirements described in this report. Compared with the anthracene and tetracene, the fluoranthene based formulation has the advantage of being efficient under standard room lighting. Samples of both these formulations will be delivered to the technical representative of the Naval Training Device Center for further evaluation.

APPARATUS MODIFICATION

In the initial testing it was felt that there might be some advantage in reducing the temperature of the coils in the smoke generator. It was thought that this might reduce the tendency of the high heat to completely destroy the chemicals in the formulation, during the process of generating the cloud. Reducing the heat of the coils, it was felt, would encourage a partial combustion. This would cause more smoke and possibly allow some of the fluorescent particles, in a finely divided state, to pass through the generator and appear in the cloud. However, testing indicated that the response of the suggested fuel formulations is relatively unaffected by changes in the temperature of the heating coils. Also, changes in the pressure driving the fuel to the coils has little effect on the response. Therefore, it is suggested that no significant changes in the smoke generator be made for the utilization of the suggested smoke fuels.

VI RECOMMENDATIONS

SYSTEM CAPABILITY EXTENSION

To enhance the response of the smoke cloud, it is suggested that a small ultra-violet light be included in the smoke generator apparatus. This would provide a high concentration of ultra-violet rays at the base of the smoke cloud. The light could be controlled by the solenoid which would allow it to burn for a specific period of time to approximate the time it takes for the cloud to dissipate.

It is also suggested that devices for control of the shape and action of the cloud be investigated. It is possible that the column of smoke could be shaped into a low ground hugging cloud, a tall pillar shaped cloud or a mushroom shaped cloud with intense swirling action. Such control would result if the shape of the smoke generator orifice was varied.

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Naval Training Device Center Orlando, Florida

13. ABSTRACT

The smoke fuels described in this report serve, in conjunction with the X3H14 smoke generator, to accomplish smoke clouds which are sensitive to ultra-violet light excitation; that is, the smoke cloud is luminescent when exposed to GE BLB 40 W and GE BL 40 W bulbs. The smoke clouds are luminescent and dissipate cleanly after a few seconds. This report covers the program of literature and bench research conducted in development of these formulations.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
EXPLOSIVE SIMULATION						
DEVICE X3E4						
SMOKE GENERATOR						
FLUORESCENT SMOKE CLOUD						
ULTRA-VIOLET LIGHT						

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